SCIENCE

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MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Prof. J. McKeen Cattell, Garrison-on-Hudson, N. Y.

*THE IMPORTANCE OF ASTROPHYSICAL RESEARCH AND THE RELATION OF ASTROPHYSICS TO OTHER PHYSICAL SCIENCES**

THE domains of the physical sciences are not, like the political divisions represented on a map, capable of being defined by boundary lines traced with mathematical precision. They pass into one another by imperceptible gradations, the unity of nature opposing itself to rigid systems of classification. Thus there often exists between two allied sciences a broad ground, belonging to each, yet exclusively the property of neither, which may be so extensive and fertile as to justify the development of a new science for its special cultivation. And such a science not only subserves the purpose for which it was created, but it has the further special importance that, by promoting an exchange of knowledge between its previously established neighbors, by investigating the cause of disagreements between them, by comparing their methods, and possibly by detecting errors in their results, it tends to bring them into more perfect coordination.

Such is the nature of the science which Professor Langley has called the new astronomy, and which is also, and perhaps more generally, known as astrophysics. Its

*Address delivered at the dedicatory exercises of the Yerkes Astronomical Observatory, of the University of Chicago, Williams Bay, Wis., Thursday, October 21, 1897.

high development has in fact been so recent that its name is found in only our latest dictionaries. It is closely allied on the one hand to astronomy, of which it may properly be classed as a branch, and on the other hand to chemistry and physics; but it assumes wide privileges, and it is ready to draw material which it can use with profit, from any source, however distant. It seeks to ascertain the nature of the heavenly bodies, rather than their positions or motions in space—*what* they are, rather than *where* they are; and for my own convenience I shall use the terms astrophysics and astronomy to denote the sciences of which these aims are respectively characteristic. Yet here again the line of demarcation cannot be sharply drawn, since the measurement of celestial motions that cannot be dealt with by the methods of the older astronomy is one of the most important tasks of the astrophysicist. That which perhaps is most characteristic of astrophysics is the special prominence which it gives to the study of radiation. The complex nature of white light, in particular, is never lost sight of, and its consequences are thoroughly exploited.

That the older astronomers made no efforts systematically to study the nature of the heavenly bodies, is to be ascribed to the seeming hopelessness of such an attempt in their day, rather than to a lack of interest in the subject, or a slight appreciation of its importance, on their part. They did, in fact, seek explanations of such phenomena as they could observe, and the beginnings of astrophysics are to be found far back in the past. But the curious speculations of Sir John Herschel on the structure of the sun's photosphere show how inadequate was the supply of facts to serve as a basis for a science of solar physics in Herschel's time. The conception of living organisms a thousand miles long, floating about on the sun's surface, and shining with the intense brilliancy of the photosphere, seems to us extraordinary, and even grotesque. To lose its strangeness it has to be considered with reference to the contemporary state of knowledge. But the fact that only fifty years ago it was regarded as an admissible supposition by one of the most eminent of astronomers helps us to realize how rapid has been the advance of astrophysical science. It was only after the discovery was made, that the light which reveals to us the existence of the heavenly bodies also bears the secret of their constitution and physical condition, that the basis for a real science was obtained. The spectroscope placed new and hitherto undreamed-of powers in the hands of men. It is to the astrophysicist what the graduated circle and the telescope are to the astronomer.

The study of astrophysics does not at present seem to have a very direct bearing on the practical affairs of everyday life. If to this statement the objection should be made that the study of solar radiation is likely to lead to a practical method of utilizing the sun's heat as a source of mechanical power, I should say that such a discovery (if it is ever made) is much more likely to be the result of an ingenious application of principles already known. What the future may have in store we cannot tell, but at present the statement I have made holds good. With respect to practical usefulness, therefore, astrophysics does not possess the same claims to consideration as astronomy, which has obviously important applications in furnishing standards of time, and in surveying, geodesy and navigation, and in addition to these, an immense indirect influence on thousands of ordinary affairs. Yet on such grounds it is not probable that any astronomer would care to base a claim for his science. Astronomy long ago reached that state of perfection which suffices for the practical ends

I have mentioned, and is still pursued with undiminished vigor. Both astronomy and astrophysics take their stand on a higher plane, where it is a sufficient justification for their existence that they enable us better to understand the universe of which we form a part, and that they elevate the thoughts and ennoble the minds of men.

In considering the importance of astrophysical research, I have, therefore, regarded the question from a purely scientific point of view. Even with this restriction there is room for a considerable diversity of opinion, since the elimination of the human element from the question is impossible. Scientists are men. Every man is naturally inclined to attach special importance to that in which he is himself specially interested. Personal preferences, or even prejudices, may enter into the estimation in which a branch of learning is held. But, setting these aside, there are grounds for differences of opinion which are entitled to respect. What importance is to be attached, for example, to the proof, now brought almost within our grasp by the improvement of spectroscopic instruments and methods, that the law of gravity is operative within the stellar systems, as well as in the system of our own sun? Doubtless there are some who are satisfied with the moral certainty that we already possess, and to whom the proof just mentioned would merely afford the satisfaction of inking in, on a printed form, the penciled words which had already been written in its blanks; while there are others who would regard the formal proof as alone entitled to consideration. I have even heard widely different opinions expressed by eminent astronomers as to the scientific importance of a problem so fundamental as the exact determination of the distance of the sun.

The degree of importance which we attach to a newly discovered fact or principle is influenced by many circumstances, among which we cannot fail to recognize some of the failings of human nature. When progress is rapid, individual achievements lose their prominence, like mountain peaks rising from a high plateau. The discovery of an asteroid was once a notable event. Now it attracts little attention, outside of a small circle of observers, and it is probable that few of us could say just how many of these little bodies have been brought to light during the past year. In astrophysics discoveries of the highest significance have succeeded one another so rapidly that they are now taken as a matter of course.

The bearings of a discovery on existing knowledge are sometimes not immediately perceived, and its true scientific importance is not appreciated until these are revealed in the fullness of time. Other circumstances might be mentioned, but these are sufficient for my purpose, which is to show that there is no cause for surprise if opinions differ as to the exact value of astrophysical research. It is because the science of astrophysics is so young—so distinctly in the formative stage—that I have ventured to discuss a question which, in due time, will settle itself.

A feature of astrophysical research which I do not wish to leave unmentioned is the interest which is felt in it by the public. Those who are interested in the results of science, but who care little for methods, and know nothing of elegant forms of analysis, are naturally more attracted by the view of the heavenly bodies which astrophysics presents than by the view which is obtained from the standpoint of the older astronomy. Astrophysics paints its picture in the brighter colors. A star regarded as a center of attraction, or as a reference point from which to measure celestial motions, awakens little enthusiasm in the popular mind; but a star regarded as a sun, pouring out floods of light and

heat as a consequenee of its own contraction, torn by conflicting currents and fiery eruptions, shrouded in absorbing vapors or perhaps in vast masses of flame, appeals at once to the popular imagination. Both branches of astronomy share in the advantages which follow this awakening of popular interest; for that popular interest in any science is to be deprecated is to my mind utterly inadmissible. The cultivation of a pure science is possible only in those communities where such an intelligent interest exists. Without it we should not be here to-day. It is splendidly manifest around us. The only possible danger to be feared is that interest in results whose significance is readily understood may lead to an undervaluation by the public of results which are of the highest importance, but which only the trained specialist can fully comprehend; and this danger will be avoided if scientific men publicly express their own appreciation of results which belong to the latter class.

Popular interest which is not of this character, but which has no purpose other than amusement, is less desirable. "It is the universal law," says Macaulay, "that whatever pursuit, whatever doctrine, becomes fashionable, shall lose a portion of that dignity which it had possessed while it was confined to a small but earnest minority, and was loved for its own sake alone." Macaulay is here referring to a temporary interest in scientific matters which prevailed among fashionable circles in the reign of Charles the Second—to what would now be called a 'fad.' In our own time science occasionally suffers in much the same way. It is to be regretted that the habitability of the planets, a subject of which astronomers profess to know little, has been chosen as a theme for exploitation by the romancer, to whom the step from habitability to inhabitants is a very short one. The result of his ingenuity is that fact and fancy become inextricably tangled in the mind of the lay man, who learns to regard communication with the inhabitants of Mars as a subject deserving serious consideration (for which he may even wish to give money to scientific societies), and who does not know that it is condemned as a vagary by the very men whose labors have excited the imagination of the novelist. When he is made to understand the true state of our knowledge of these subjects he is much disappointed, and feels a certain resentment towards science, as if it had imposed upon him.

Science is not responsible for these erroneous ideas, which, having no solid basis, gradually die out and are forgotten. Thus it cannot long suffer from outside misapprehension, while the sustained effort necessary to real progress is in the end a sufficient safeguard against the intrusion of triflers into its workshops.

In astrophysics sustained effort is as necessary as it is in other branches of science. There is an impression in some quarters that the results of astrophysical investigation are easily obtained. That this is in some cases true may readily be admitted. I cannot regard it as a reproach. It is one of the advantages to which I have referred by bringing new methods to bear on old problems. What an effort to grasp something tangible we observe in the earlier writing on Fermat's principle! What a groping in the dark after a principle felt rather than seen! and how obvious the same principle is from the point of view of the wave theory! In a field so wide and so little explored as astrophysics there must be novelties which can be gathered with comparatively little effort, and which may nevertheless be of no small importance. But there are also problems whose solution calls for the exercise of the highest intellectual faculties, and for the most strenuous exertion.

In astrophysics difficulties are met with

quite different from those of physical astronomy. There a vast variety of highly complex phenomena are to be referred to the operation of a well-known and extremely simple law. The mental discipline there obtained is of the highest order, and it is hardly necessary to say that a training in the methods of the older astronomy should be regarded as an indispensable preparation for astrophysical work. But in astrophysics, as in the sciences of chemistry and biology, there are difficulties which arise from an imperfect knowledge of the laws governing the phenomena observed. The discovery of unknown laws and principles, as well as the explanation of phenomena by laws already known, is one of its most important objects.

I have referred to the differences of opinion which usually exist with reference to the value of a new science. There may be some who view with disfavor the array of chemical, physical and electrical appliances crowded around the modern telescope, and who look back to the observatory of the past as to a classic temple whose severe beauty had not yet been marred by modern trappings. So mankind, dissatisfied with present social conditions, looks back with tender regret to the good old times of earlier generations, yet rushes forward with the utmost speed. May we regard the eagerness of pursuit as a measure of the value of its object? That the importance of astrophysical research, considered with respect both to its own ends and to its bearing on the advance of knowledge in other fields, is already great, and that it will grow steadily from year to year, is naturally my own belief. In a general way I have considered some of the reasons on which it is founded, and I now wish to call your attention to a few specific cases which illustrate my general remarks, and in which I think the importance of astrophysical science is manifest.

Some of the most noteworthy advances in astronomy and in astrophysics have been made possible by the introduction of photography. The photographic plate not only gives a permanent record of what the eye can see, but, by its integrating power continued through long exposures, it builds up a picture from light impulses too feeble to affect the sense of vision. Thus it has been discovered that vast regions in the sky are filled with diffuse nebulæ, which (since the apparent brightness of a surface cannot be increased by any optical device) must ever remain unseen. This information, which the photographic plate alone could furnish, is itself most wonderful and suggestive. It is, however, but a part of what the same plate may yield. Whoever has studied Professor Barnard's admirable pictures of the Milky Way in Scorpio must have observed how accurately the distribution of the smallest stars corresponds to that of the extended nebulosity which fills this part of the sky, and at the same time how strikingly the nebulous matter is concentrated around the brightest stars in the constellation. Bright stars, faint stars and nebulosity are unmistakably physically related, and, hence, at the same order of distance from the earth; and from this it follows that the real sizes of the stars are of entirely different orders. Here is a fact having a most important bearing on the question of stellar distribution, brought out by the simplest possible means. It is perhaps beyond the reach of more elaborate methods. And in this case it is to be observed that the evidence would not be made clearer by any further treatment of the material. The positions of the stars and the density of the nebulosity might be measured, and the results might be tabulated, but all to no purpose; for, if the data yielded by observation were in the form of measurements, the first step toward their interpretation would be the construction of just such a

chart as the photograph places ready in our hands.

Of very great importance to the new astronomy has been the investigation of the conditions of maximum efficiency of its chief instrument, the spectroscope, by the methods of physical optics. The theory of resolving power, introduced by Lord Rayleigh, and quite recently elaborated by Professor Wadsworth, has been especially fruitful. It has done away with the old idea that the efficiency of a spectroscope is measured by its dispersion, and may be trusted to destroy in time some musty traditions concerning the magnifying power and definition of astronomical telescopes. The theory has also been extended so as to include the spectrograph, in which the photographic plate takes the place of the eye at the observing telescope of the spectroscope. The designing of spectroscopes has thus been placed on a thoroughly scientific basis. At the same time the demands for accuracy in the practical construction of the instrument have been greatly raised. The objectives, the prisms, the fitting of the mechanical parts, must be the best possible. Hence the spectroscope has become an instrument of precision, worthy of a plaee among the most refined instruments of practical astronomy, and fitted for the class of work now most needed in astrophysical research.

A familiar example of the mutual obligations of allied sciences is found in the first measurements of the velocity of light. Perhaps a somewhat parallel case may have to be recorded by the future historian of science. Spectroscopists have tested the validity of what is known as Doppler's principle, by which the motion of a body in the line of sight is determined from the observed displacement of its spectral lines, and have at the same time proved the capabilities of their instruments, by means of the velocities of the earth and heavenly bodies furnished to them by astronomy. It is not impossible that this also is a reversible process, and that measurements of the velocities of bodies in the solar system may give one of the best methods of determining the dimensions of their orbits.

Numerous cases could be mentioned in which astrophysical investigations have contributed to our knowledge of the chemical elements. Of these the first which naturally presents itself is one of the most recent. The element helium was discovered first in the sun (as its name implies), then in the stars, then in the nebulæ, and at last, by Professor Ramsay, it was 'run to earth.' It had an important place in celestial chemistry long before it was known to terrestrial science; and, on account of its rare occurrence and seeming inertness, it is quite possible that but for the spectroscope of the astrophysicist we should have remained forever ignorant of its existence. To the astrophysicist, however, it was known only by the occurrence in its spectrum of one bright line. Laboratory investigations soon revealed its complete spectrum, and then the astrophysicists were able to recognize, as belonging to helium, a large number of lines whose origin in the heavenly bodies they had been unable to discover. Our knowledge of the heavenly bodies may be greatly advanced when the properties of this remarkable element shall have been thoroughly studied.

It is not necessary, however, to seek illustrations in new elements. The complete series of hydrogen lines, to which belong the few lines that are ordinarily seen in the laboratory spectroscope, was discovered by Huggins in the spectra of the white stars; and a new series, which had previously been seen by the eye of theory only, and which, so far as I know, has not yet been produced artificially, has recently been found by Pickering in the spectrum of the star *Zeta Puppis*.

Another familiar element is calcium. Its

ordinary properties are well understood. But under the conditions met with in the sun and stars it behaves in a mysterious manner. Notwithstanding its considerable atomic weight, it floats quietly high above the surface of the sun, where other heavy metals are only occasionally present in consequence of violent eruptions. It is true that the apparently abnormal spectrum of calcium under these conditions has been shown by Sir William and Lady Huggins to be merely the result of extreme tenuity of the luminous vapor; but the existence of calcium at such great heights, under any conditions whatsoever, seems to point to some remarkable property of the element which is unrecognizable by the methods of ordinary chemistry.

The spectrum of a substance is not the same under all circumstances. In some cases a change occurs suddenly when certain critical conditions are reached; in others the change is gradual and progressive. By studying these changes in laboratory experiments, and comparing them with what we see in the observatory, we are able to arrive at some definite conclusions respecting the conditions which prevail in the stars, while the same comparison often throws light on the phenomena observed in the laboratory. It has been shown, for instance, that the spectrum of magnesium gives a means of estimating the temperatures of the stars; and the same criterion enables us to recognize in the stars temperatures vastly exceeding the highest that have been produced on the earth. Thus the science of astrophysics allows us to extend our investigations to temperatures which the resources of the laboratory cannot furnish.

It may be well to mention an example of the difficulties, to which I have referred, arising from our imperfect knowledge of the laws which underlie phenomena constantly observed. Recent comparisons of the spectra of the sun and metals, made at the Johns Hopkins University with the concave grating spectroscope of Professor Rowland, have proved that spectral lines may not merely be widened by increased pressure of the radiating vapor, but that they may be shifted bodily; while the still more recent investigations of Zeeman show that a line may be widened (and at the same time doubled) under the influence of a strong magnetic field. It is true that in both cases the effect produced is very small. It could not lead to mistakes in identifying stellar lines, or to appreciable errors in measuring celestial motions. But the fact that the spectrum of a substance varies according to circumstances which are as yet only imperfectly understood, shows us the necessity of exercising caution in interpreting the spectral phenomena presented to us by the heavenly bodies. At present these spectral variations increase the difficulties that the astrophysicist has to contend with. Eventually they will become additional and most valuable sources of information.

The discovery, by Kayser and Runge, of line series in the spectra of the common elements has a most important bearing on the work of the astrophysicist. It provides him with the means, long greatly needed, of deciding with certainty whether or not lines in celestial spectra are identical with lines in the spectra of terrestrial substances. On the other hand, as we have already seen, he is sometimes able to supply the physicist with missing data.

From the point of view of the old astronomy the most important result of the introduction of the new methods has been the determination of motions in the line of sight by means of the spectroscope. The method has been tested so often, and with such uniform success, that there is no longer any doubt as to the correctness of the principle on which it is based, or to the accuracy of the results which it is capable of yielding

in competent hands. It is directly applicable to one of the great problems of astronomy—the determination of the direction and rate of the sun's drift through space. From the proper motions of the the stars, furnished by the methods of the older astronomy, the direction of the sun's motion can be deduced, and, under certain assumptions as to the stars' distances, the rate of motion; but it is evident that the latter element of the problem must be subject to very considerable uncertainty. With the spectroscope velocities are directly measured in miles per second. The two methods may be combined. It is probable that the most accurate determination of the *direction* of the sun's drift can be obtained by preparing proper motions, while the most accurate value of the *velocity* is that given by the spectroscope. Thus by the cooperation of the two branches of astronomy, there is measured in space a base line of constantly increasing length for a great sidereal triangulation. At present the material afforded by spectroscopic observation is not sufficient for this great work. The observations must be treated statistically, and statistical methods can be applied successfully to only a large mass of data. What is now needed, therefore, is observations of more stars, *i. e.*, fainter stars, and the German government is building a large telescope for the observatory at Potsdam (where photography was first applied to this class of observations), in order that the work may be continued. There is room, however, for the employment of other large telescopes in the same field. The multiplication of observations for this purpose is no more to be deprecated than the multiplication of observations for the exact determination of star places.

Solar physics, from which the wider science of astrophysics has been evolved, offers problems so numerous and so complicated that I cannot even mention them, still less enter into a discussion of their bearing on other branches of knowledge. And what can I possibly say of their importance? The sun is to us the grandest of material objects. It is the source of practically all our light and heat; of practically all our mechanical power; absolutely the support of all our lives. What wonder that we seek for knowledge of its nature by all the ways that we can find! These ways are opened through astrophysical research. In few of the inquiries that I have referred to can the method of light analysis be dispensed with. In most of them it offers the only chance of success.

I have time to mention only one new method of solar research. The most notable contribution to solar physics within the last few years has been the invention of the spectroheliograph by Hale and Deslandres. With this instrument photographs of the sun are taken by strictly monochromatic light, which may be chosen from any part of the spectrum. If the part selected is the middle of the K line, the picture essentially represents the distribution of calcium vapor on the disk of the sun, and the presence of other elements is ignored. This is, in fact, the line usually chosen, partly on account of the conspicuous rôle played by calcium in solar phenomena, and partly for other reasons, which it is not necessary to state. The possibilities of the method are obvious. By an ingenious modification of his instrument Hale now photographs on a single plate the Sun covered with all its spots and faculæ, and surrounded by all its prominences; and all this is done in a few minutes, in full daylight! Could the corona be added, the triumph would be complete; but the corona yet remains unconquered in its stronghold, though the attack is being vigorously pushed.

No branch of observational astronomy seems to be in so backward a state as the

representation of the surface features of the planets. Although the moon has been photographed with splendid success, and the planets with results that are encouraging and suggestive, we still rely (in the case of the planets) on the old method of hand drawing used by Galileo. The fallibility of the draftsman is well known. It has been illustrated again and again. Yet there seems to be a curious habit among some observers of regarding a drawing, when once made, as invested with high authority —as that of a standard established by legislative act. A photograph, if it could be made, would be free from the errors of the draftsman, and from a personality which is recognizable in all hand drawings, and which, though it is scarcely to be classed as an error, it would be desirable to avoid. Here, then, is another opportunity for the new methods. There is no reason to suppose that it is impossible to obtain photographs of the planets which will show all that the eye can see, although there are many reasons to know that it will be very difficult to do so. The instruments for this purpose would have to be quite different from those in general use, and there would be few occasions, in even the most favored regions of the earth, when they could be employed. Difficulties would also arise from the rapid rotation of some of the planets. But this is not the place to discuss the necessary conditions. It is only fair to say that Professor Schaeberle, of the Lick Observatory, has already been experimenting in this direction—with what success is not yet generally known.

Passing to stellar spectroscopy, a field broader even than that of solar physics is opened before us; for the sun, although paramount in his own system, is only one of the stars. In a general way, the spectra of the stars have been observed, and classified according to their character, and objects of unusual interest have been noted for future investigation—many a rare specimen has been meshed in Harvard's widely extended net; but the detailed study of individual spectra has just begun. For this purpose large telescopes are desirable, if not absolutely necessary. Many observations of precision required in the older astronomy are best made with small telescopes. But in stellar spectroscopy light is all-important; and while much can doubtless be accomplished with small telescopes, there is probably nothing that cannot be done better with large ones. Even in solar spectroscopy, where the supply of light is abundant, a large image is required for the study of individual parts of the sun's surface.

No department of astrophysics has profited more by the introduction of photographic processes than stellar spectroscopy. To the advantages of photography already mentioned there is here to be added another not less important. Owing to atmospheric disturbances the image of a star dances about on the slit-plate of a spectroscope placed in the focus of a telescope. The spectrum is not only faint, but tremulous, and to measure the lines in it by visual observation is like trying to read a printed page irregularly illuminated by flashes of light. These irregularities do not appear on the photograph. They disappear in the process of integration. Negatives obtained with the spectrograph can be directly measured under a microscope, or enlargements can be made from them in the usual manner. In this way photographs of star spectra are now made which are comparable, with respect to accuracy and wealth of detail, to Kirchhoff's famous map of the solar spectrum. "It is simply amazing," says Professor Young, with reference to the Draper memorial photographs, "that the feeble, twinkling light of a star can be made to produce such an autographic record of substance and condition of the inconceivable distant luminary."

Let us consider for a moment some of the questions in this field that are open for investigation. The motions in the line of sight of all stars within reach of the largest telescopes have to be measured. This important line of research has already been referred to. The relation has to be ascertained between the various classes of star spectra and the probable order of stellar evolution. It now appears practically certain that all the stars are not made according to a single pattern, and that they cannot be fitted into a single scheme of development. The Wolf-Rayet stars, the stars with banded spectra, the stars with bright-line spectra, the planetary nebulæ, the spectroscopic binaries, the variable stars, require the most careful attention. Variables of the Mira class should be followed with the spectroscope as far as possible from their maximum, and the spectral changes which accompany the light variation of other stars, whether due to phenomena of emission and absorption, or to relative motion of bodies in a revolving system, should be studied with the most powerful instruments.

The discovery, by means of the spectroscope, of binary stars which are far too close for resolution with our most powerful telescopes, and which are recognized in their true character by a periodic doubling of their spectral lines, has brought to our knowledge strange and wonderful conditions of orbital motion. Such a system as that of Spica, where two bodies like our sun revolve around each other like the balls of a gigantic pendulum, in a period of only four days, at a distance no greater than that which separates the sixth satellite of Saturn from its primary, must have remained forever unknown to the older astronomy. Between these spectroscopic binaries and the most rapidly revolving doubles visible in the telescope there is a wide gap, the cause of which is obvious. The conditions favorable to discovery in the two cases are directly opposed, and doubtless a large class of stars lies at present just beyond the reach of either method.

But this gap may be bridged over by means of such a great telescope as we see before us to-day, while the work necessary to accomplish this end will open up still another field for research. It has long been recognized that the position micrometer and the spectroscope, taken together, are theoretically competent to determine the real orbits in space of the components of a double star; hence, also, the masses of the components and their distance from the earth. Until recently the question had only a mathematical interest. But the small velocities to be expected in the case of any double star whose components can be separately distinguished with the telescope are now almost, if not quite, within reach of the spectroscope, and the investigation of such doubles has acquired a physical interest.

Here I must close my review of the important questions before the astrophysicist, with the consciousness that it is most remarkable for what it leaves unnoticed. I have said nothing of questions relating to the photography of comets and their spectra, the rotation of the planets or the absorption spectra of their atmospheres, the colors of double stars, the spectra of temporary stars, the measurement of obscure wave-lengths; nothing about stellar photometry, the application of interference methods to spectroscopic research, the exploration of the infra-red spectrum. But I will not trespass further on your patience. In all the fields that I have mentioned there are noble problems, worthy of the best efforts that can be given to their solution. To realize their importance, think how ill we could spare what we have already won. What a blank would be left in our knowledge of the heavens if the results of astro-

physical research in our own generation were stricken out!

The future should look bright, indeed, as we view it to-day. Munificence and skill have provided this splendid observatory with means for promoting knowledge in both the older and the newer branches of the sublime science to which it is dedicated. Its magnificent equipment will be used by men who have won merited distinction in both the older and the newer methods of research. It has the cooperation and support of a great institution of learning. From this happy union of ability and opportunity we have reason to expect results of the highest import to the new astromony, and to its allied branches of physical science.

But, lest any words of mine should give rise to expectations that may not be fulfilled, I wish to say once more that important results are not necessarily of a striking or surprising character. We can hardly assume that every increase in telescopic power will be followed by the discovery of new planets or satellites. Such discoveries, if they come, will be welcome; but they should not be expected. There may be no more planets or satellites, yet undiscovered, in the solar system. But we may confidently expect from the work of this observatory those results which throw light on the dark places in nature, and which, therefore, though they may not stimulate the popular imagination, are of the very highest importance, for they are indispensable to true scientific progress.

JAMES E. KEELER.

ALLEGHENY OBSERVATORY.

MATHEMATICS AND ASTRONOMY AT THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

THE officers of the Section of Mathematics and Astronomy were as follows: Chairman, W. W. Beman; Secretary, J. McMahon; Press Secretary, P. A. Lambert; Councillor, E. W. Hyde; Sectional Committee, W. W. Beman, J. McMahon, A. Macfarlane, W. F. Durand, J. E. Kershner, W. S. Pritchett; Member of Nominating Committee, A. Ziwet; Committee to nominate officers of Section, W. W. Beman, J. McMahon, A. Hall, Jr., R. S. Woodward, A. Macfarlane.

The Chairman's address was on 'A Chapter in the History of Mathematics,' which has already been published in this JOURNAL.

The following papers were presented to the Section:

1. A Problem in Substitution-groups. By Dr. G. A. Miller, Rosette, Kan.

2. Continuous Groups of Spherical Transformations in Space. By Professor H. B. Newson, Lawrence, Kan.

3. The Treatment of Differential Equations by Approximate Methods. By Professor W. F. Durand, Ithaca, N. Y.

4. Commutative Matrices. By Professor J. B. Shaw, Jacksonville, Ill.

5. On the Theory of the Quadratic Equation. By Professor A. Macfarlane, Lehigh University, South Bethlehem, Pa.

6. A New Principle in Solving Certain Linear Differential Equations that occur in Mathematical Physics. By Professor A. Macfarlane, Lehigh University, South Bethlehem, Pa.

7. Condition that the Line Common to $n-1$ Planes in an n-space may Pierce a Given Quadric Surface in the Same Space. By Dr. Virgil Snyder, Ithaca, N. Y.

8. The Psychology of the Personal Equation. By Professor T. H. Safford, Williamstown, Mass.

9. Compound Determinants. (Preliminary communication.) By Professor W. H. Metzler, Syracuse, N. Y.

10. Waters within the Earth and Laws of Rainflow. By W. S. Auchincloss, C.E., Philadelphia, Pa.

11. On the Secular Motion of the Earth's Magnetic Axis. By Dr. L. A. Bauer, University of Cincinnati, Cincinnati, O.